Canadian Aviation Safety Board

Bureau canadien de la sécurité aérienne

Civil Aviation Occurrence Report

Canada

The Canadian Aviation Safety Board investigated this occurrence for the purpose of advancing aviation safety. It is not the object of the Board to determine or apportion any blame or liability.

AVIATION OCCURRENCE REPORT

PACIFIC WESTERN AIRLINES LTD
BOEING 737-275 C-GGPW
KELOWNA AIRPORT, BRITISH COLUMBIA
14 JULY 1986

REPORT NUMBER 86-P64053

SYNOPSIS

The aircraft was on a scheduled flight from Calgary, Alberta to Kelowna, British Columbia. The flight landed at Kelowna shortly after a torrential rain storm had occurred. During the landing roll, the aircraft hydroplaned, the thrust reversers and ground spoilers did not deploy, and the aircraft overran the runway.

The Canadian Aviation Safety Board (CASB) determined that the pilot's landing procedures on the wet runway, combined with limitations imposed by the aircraft air/ground logic system, prevented deployment of the ground spoilers and reversers. As a consequence, the crew was unable to stop the aircraft on the runway.

Ce rapport est également disponible en français.

29 June 1988

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1.0 FACTUAL INFORMATION

1.1 History of the Flight

Pacific Western Airlines (PWA)* Flight 117 departed Calgary International Airport, Alberta at 1942 Pacific daylight time (PDT)** on 14 July 1986, on a scheduled instrument flight rules (IFR) flight to Vancouver International Airport, British Columbia with an en route stop at Kelowna, British Columbia.

The aircraft, a Boeing 737, C-GGPW, flown by the first officer from the right seat, departed from runway 28 at Calgary and climbed to its assigned altitude of flight level 310***.

En route to Kelowna, the captain contacted the company dispatch office in Calgary and obtained the weather for Kelowna. This weather sequence was nearly one hour old at the time, so the captain advised the first officer to delay the approach briefing until updated weather was received. Descent clearance was obtained from air traffic services in Vancouver, and, at 2010 PDT, the captain contacted the Kelowna air traffic control (ATC) tower. The tower controller advised the flight that runway 33 was in use, surface winds were 300 degrees at 15 to 20 knots with occasional gusts to 25, and torrential rain and gusty winds associated with a storm cell that was moving toward the airport from the northwest were present. Lightning had been observed to the south. The captain responded that if the conditions persisted he would hold over the Kelowna non-directional beacon (NDB) until the weather improved. He then advised the passengers of the weather and his intention to delay the landing.

The first officer conducted the briefing for the approach to runway 33. This briefing included a request for the captain to monitor the automatic deployment of the spoilers and deploy them manually if the automatic system failed to do so. On the descent, the aircraft broke out of cloud prior to reaching the minimum en route altitude (MEA), and the descent was continued visually. The crew sighted the airport, observed that

* See Glossary for all abbreviations and acronyms.

** All times are PDT (Coordinated Universal Time (UTC) minus seven hours) unless otherwise stated.

*** Units are consistent with official manuals, documents, reports, and instructions used by or issued to the crew.

the storm had moved to the east away from the airport, and decided not to hold at the NDB but to continue with the approach. The aircraft was levelled at 5,500 feet above sea level (asl) and passed to the west of the airport about 4,000 feet above airport elevation. At 2021 PDT, a left descending turn was commenced onto the final approach path. The captain transmitted the aircraft's position to ATC and was advised that the flight was cleared to land, the surface winds were 030 degrees at 10 knots, and the runway was very wet.

The pre-landing checks were completed, and a visual approach was conducted in light rain. The planned threshold speed was 125 knots adjusted to 135 knots to allow for the wind conditions at the airport. During the approach, the captain advised the first officer to be aware of airspeed fluctuations under the prevailing weather conditions and to land the aircraft firmly. As the aircraft approached the runway, ATC advised that the winds were 030 degrees at 5 to 10 knots (See Appendix A). At 100 feet above ground level (agl), the captain, at the first officer's request, turned the windshield wipers on. The crew reported that, as the aircraft was flared for touchdown, it was subjected to a gust of wind. Touchdown occurred at 2025 PDT just as the captain advised the first officer to "get her on." The landing was very smooth, between 1,500 and 1,800 feet down the runway at a speed of 135 knots with 70 to 75 per cent N1 rpm on the engines. After touchdown, the first officer retarded the thrust levers, applied the brakes, and attempted to select reverse thrust. When the first officer was unable to move the thrust levers into the reverse position, he advised the captain who also tried unsuccessfully. The captain also applied full brakes. Braking was ineffective, and, with the end of the runway rapidly approaching, the captain shut down the engines by placing the engine start levers to the cut-off position.

The aircraft left the end of the runway and came to rest approximately 1,300 feet beyond the end of the runway, 90 feet to the left of the extended centre line.

The captain ordered an evacuation of the passengers which was carried out under the direction of the cabin crew.

The incident occurred at 2025 PDT during the hours of daylight, at lat 49°58'N, long 119°23'W, on the airport which has a reference elevation of 1,409 feet asl.

1.2 Injuries to Persons

	Crew	Passengers	Others	Total
Fatal	-	-	-	-
Serious	-	-	-	-
Minor/None	5	76	-	81
Total	5	76	-	81

1.3 Damage to Aircraft

Damage to the aircraft was limited to the main landing gear tires. All four tires had a flattened area in which there were deep gouges and devulcanized rubber tread. When the aircraft was examined, prior to removal from the overrun area, the damaged area of each tire was in contact with the ground and not visible. The undamaged tire tread area had a tread depth of 1/8 to 5/16 of an inch. Tires are normally changed when the tread depth is less than 1/32 of an inch.

1.4 Other Damage

- Nil -

1.5 Personnel Information

1.5.1 Flight Crew

	Captain	First Officer
Age	43	41
Pilot Licence	Airline Transport	Airline Transport
Medical Expiry Date	01/10/86	01/11/86
Total Flying Time	12,200 hr	5,500 hr
Total on Type	5,000 hr	3,200 hr
Total Last 90 Days	100 hr	50 hr
Total on Type Last 90 Days	100 hr	50 hr
Hours on Duty Prior to Occurrence	6.5 hr	6.5 hr
Hours off Duty Prior to Work Period	17 hr	17 hr

The flight crew was qualified to fly the Boeing 737 aircraft. Route and instrument checks, simulator training, and emergency procedures training had been satisfactorily completed. Both crew members had received the off-duty time prescribed by regulations. The first officer occupied the right seat and was at the controls.

1.5.2 Cabin Crew

The flight carried a purser and two flight attendants. For the landing at Kelowna, the purser occupied the forward cabin attendant's seat, one flight attendant occupied the rear cabin attendant's seat, and the other flight attendant occupied seat 10D, which is an aisle seat adjacent to the overwing emergency exits.

The cabin crew were qualified to perform their duties and had completed the required recurrent training, including emergency evacuation procedures. They were medically fit and had received the required rest period prior to the flight.

1.6 Aircraft Information

1.6.1 General Information

Manufacturer	Boeing Commercial Airplane Co.
Type	737-275
Year of Manufacture	1978
Serial Number	21639
Certificate of Airworthiness	Valid
Total Airframe Time	19,954 hr
Engine Type (2)	Pratt & Whitney JT8D-9A
Maximum Allowable Take-off Weight	117,000 lb
Recommended Fuel Types	Jet A/Jet B

The aircraft was maintained in accordance with procedures adopted by the company and approved by Transport Canada. The aircraft was serviceable prior to the incident, and its weight and centre of gravity were within the allowable limits. The calculated landing weight at Kelowna was 88,426 pounds.

1.6.2 Ground Air Safety Sensor

The Boeing 737 has a ground air safety sensor which activates or deactivates various aircraft systems based on whether the aircraft is on the ground or in the air. This sensor is activated by a cable which is attached to the right main landing gear scissors (See Appendix B). This cable positions a sensor actuator and a hydraulic ground spoiler interconnect valve when strut compression or extension occurs. The hydraulic valve controls fluid to the ground spoilers. The sensor actuator supplies electrical power to numerous systems including the thrust reverser isolation valve and the anti-skid touchdown protection system. The amount of strut

compression required to operate the sensor is adjustable. Strut compression is measured from the fully extended position of the landing gear oleo; the manufacturer's recommended setting for operation of the hydraulic interconnect valve is 1.5 inches of strut compression with acceptable tolerances of -0 inches to +1.5 inches.

1.6.3 Engine Thrust Reversers

The Boeing 737 has a reverse thrust system on each engine to assist in deceleration during the landing roll. Reverse thrust is accomplished when two doors located at the rear of each engine open to deflect the engine exhaust flow forward.

Reverse thrust is commanded by raising and rotating rearward, a thrust reverser lever for each engine. From the stowed position to full reverse thrust, the levers travel 130 degrees which represents a hand travel of about 10.7 inches. If the forward thrust levers are not at idle, a non-adjustable pawl mechanism limits movement of the reverse thrust levers to 20 degrees or about 1.6 inches of hand movement. This amount of movement will not initiate any reverse thrust commands.

There is an interlock mechanism that limits movement of the reverse thrust levers to 80 degrees or about 6.6 inches of hand movement. This position of the reverse thrust levers will command reverse thrust. However, the ground air safety sensor must indicate that the aircraft is on the ground before the isolation valve will open, allowing hydraulic pressure to position the reverser doors into the reverse thrust position. When the reverser doors are properly positioned for reverse thrust, the interlock is no longer engaged, and the reverse thrust levers can be moved up to full travel (130 degrees) to modulate engine power. If the interlock remains in place because the reverser doors are not in the reverse thrust position, holding the reverse thrust levers against the interlock can produce an increase in forward thrust. There is a caution to this effect in the Airplane Operations Manual.

Two thrust reverser override switches, one for each engine, are located in the cockpit on the aft section of the overhead panel. These switches are guarded, and the guards are witness-wired. Placing the switches to the override position bypasses the ground air safety sensor and the engine low oil pressure logic circuits to allow certain reverse thrust ground maintenance procedures to be carried out. As well, activation of the switches allows hydraulic pressure to reach the reversers while the aircraft is in flight to close a reverser that may

have opened or partially opened. The Boeing 737 Operations Manual states that "the override switches should not be used by flight crews for normal operations in flight or on the ground."

1.6.4 Flight and Ground Spoilers

The Boeing 737 has eight speedbrake/spoiler panels, four located on the top of each wing. Two spoilers per wing operate in flight and on the ground, and the other two per wing operate on the ground only. The spoilers are operated by the speedbrake lever which is located on the left side of the centre control stand. The lever has four positions: down, armed, flight, and up.

Placing the speedbrake lever to the armed position puts the spoilers under the control of the automatic speedbrake system. On touchdown, if the thrust levers are at or near idle, the speedbrake lever will automatically move to the up position if either wheel spin-up occurs or the ground air safety sensor indicates that the aircraft is on the ground. When the lever is up, the flight spoilers will deploy, and, if the right landing gear strut is compressed sufficiently for the ground air safety sensor ground spoiler bypass valve to open, the ground spoilers will also deploy.

The speedbrake lever may also be manually selected to the up position to deploy the flight spoilers. If the thrust levers are at or near idle and the hydraulic interconnect valve is open, the ground spoilers will also deploy. In addition, a mechanical cam on the thrust reverse levers will move the speedbrake lever to the armed position. After this action, normal automatic speedbrake logic (i.e., thrust levers retarded and either wheel spin up or main landing gear on-ground indication) will move the lever to the up position.

1.6.5 Anti-skid System

The Boeing 737 anti-skid system is designed to prevent wheel lock-up and to provide maximum braking for any runway condition. The system accomplishes this by sensing the rate of change of rotation for each wheel after initial spin-up and by applying enough brake pressure to allow the wheels to slow but not stop.

The wheels are also protected against landing in a locked condition; brake pressure can not build up until there is wheel spin-up or the ground air safety sensor signals that the aircraft is on the ground.

The anti-skid system requires alternating current (AC) in order to function. Loss of AC power will result in the wheel brakes being directly controlled by hydraulic pressure modulated by brake pedal input.

1.7 Meteorological Information

1.7.1 Forecast

The forecast for Kelowna valid from 1600 PDT on 14 July to 0100 PDT on 15 July called for scattered clouds at 5,000 and 10,000 feet with an occasional broken cloud ceiling of 5,000 feet. Cumulonimbus clouds and thunderstorms with light rain showers and winds gusting to 20 knots were forecast to be in the area until 2300 PDT.

1.7.2 Actual Weather

The Kelowna weather report for 2000 PDT, 25 minutes prior to Flight 117's arrival was eight tenths of cumulonimbus cloud based at 6,500 feet with one tenth of altocumulus cloud based at 10,000 feet; thunderstorms and light rain showers; temperature 16.8 degrees Celsius; winds 350 degrees at 10 knots; altimeter setting 29.91; and visibility 15 miles.

At 2010 PDT, as Flight 117 approached Kelowna, the tower controller advised the crew that there was a thunderstorm over the airport with torrential rain and winds 300 degrees at 15 to 20 occasionally gusting to 25 knots. By the time the flight had landed, the wind had veered to 030 degrees at six knots.

Rainfall measured at the airport in the 20 minutes prior to the flight's arrival was 4.2 millimetres. The crew reported light rain on the approach. When the tower controller issued landing clearance, he advised Flight 117 that the runway was very wet.

1.8 Aids to Navigation

The aircraft was on a visual approach to runway 33 at Kelowna. Navigation aids were not pertinent to this stage of flight.

1.9 Communications

Communications were reported to be normal throughout the flight.

1.10 Aerodrome Information

1.10.1 General

Kelowna Airport is publicly licensed and is owned and operated by the City of Kelowna. The single runway is designated 15/33 and is 5,350 feet long, 200 feet wide, with an asphaltic concrete surface. Runway 33 is equipped with a visual approach slope indicator system (VASIS) which is set for a three-degree glide path. The VASIS was on at the time of the occurrence. The touchdown elevation of runway 33 is 1,362 feet, and the runway slopes up to a high point of 1,409 feet at the end.

1.10.2 Runway Characteristics

The touchdown areas at both ends had been blackened with rubber deposits from the tires of landing aircraft. The runway is crowned with an average cross-fall of 1.32 per cent from the centre to either edge. Runway 33 slopes up for the first one third at an average of 0.7 per cent increasing to an average of 1.05 per cent for the remaining two thirds.

Runway markings conform to the standards for an instrument runway over 5,000 feet long. These markings include runway threshold marks and fixed distance markers painted on the runway every 500 feet from each end to a point 2,000 feet from the end. Runway centre line marks extend the length of the runway. There are no distance-to-go markers for either runway, nor are they a standard item at Canadian civil airports.

In the winter months, when the runway is wholly or partially covered with ice and/or snow, runway surface condition (RSC) reports are issued daily or more frequently if changing conditions warrant. In the winter months, RSC reports include a coefficient of friction measurement as determined by the James Brake Index (JBI). Runway coefficient of friction measurement devices such as the JBI can accurately measure a friction coefficient on bare, or ice- or snow-covered runways. However, they cannot do so on a very wet or water-covered runway. Thus, during periods other than winter, RSC reports are given without a JBI.

1.11 Flight Recorders

The aircraft was fitted with a Fairchild A100A cockpit voice recorder (CVR) and a Lockheed 209 digital flight data recorder (DFDR). These were removed after the incident and delivered, along with the ATC tape, to the Flight Data Playback Centre in Ottawa.

1.11.1 Cockpit Voice Recorder

The CVR was recording on all four channels, but, on two of the channels, faint voices and sounds could be heard from a previous flight. This indicates that, on two channels, the recorder erase head was not functioning correctly. The CVR stopped a few seconds after engine shutdown because of the loss of electrical power.

1.11.2 Digital Flight Data Recorder

The DFDR was recording 18 parameters providing information on altitude, airspeed, pitch, vertical acceleration, control column inputs, and engine operation. The DFDR information ceased a few seconds after engine shutdown because of the loss of electrical power.

1.11.3 Data Correlation

Correlation of the DFDR, CVR, and ATC tapes enabled a reconstruction of the final flight path to be made, and the last 500 feet of the descent is reproduced in Appendix A.

At 500 feet agl, the aircraft was on a 3.3-degree glide slope which reduced to 2.5 degrees as the aircraft approached 200 feet agl. The airspeed was stable at 135 knots to touchdown. There was no clearly defined change in vertical acceleration to identify the touchdown point, nor could the touchdown point be established directly from the DFDR data. However, from the altitude, pitch attitude, control column input, and engine parameters, it was estimated that touchdown occurred at an elapsed DFDR tape time of 28 minutes 54 seconds; this elapsed time corresponds to 2025 PDT. Coincidental with this time was the sound on the CVR of the take-off warning horn. On touchdown, the engines were at 70 to 75 per cent N1 rpm. After touchdown, the control column position recording showed a nose-down input for several seconds and engine N1 rpm decreased to about 45 per cent. Deceleration of the aircraft occurred at an average rate of two knots per second. Fifteen seconds after touchdown, the vertical acceleration indicated a peak of 1.3G. Within the next second, engine fuel flow dropped to zero, and the deceleration rate increased to 3.33 feet per second. The recordings ceased at an FDR elapsed time of 29 minutes 13 seconds while the aircraft was still at 95 knots. The precise speed of the aircraft as it left the runway could not be determined.

1.12 Wreckage and Impact Information

The touchdown point could not be determined from runway marks; the crew reported that touchdown occurred between 1,000 and 1,500 feet from the threshold. The first identifiable tire marks were located 300 feet before the end of the runway, close to the runway centre line. Immediately prior to the end of the runway, these tracks were clearly visible as white streaks. Once the aircraft ran off the runway, it began to track to the left of the extended centre line and yaw to the right. The wheels broke through the surface of the overrun area 1,229 feet beyond the runway, and the aircraft came to rest 1,340 feet from the runway, 90 feet to the left of the extended centre line. The main landing gear sank into the ground to a depth of 11 inches.

When the aircraft was examined in the overrun area, the flaps were at the flap 40 position, the speedbrake lever was up, the flight and ground spoilers were deployed, and the thrust reversers were in the stowed position.

1.13 Medical Information

There was no evidence that incapacitation, physiological, or psychological factors affected the crew's performance.

1.14 Fire

There was no evidence of fire either before or after the occurrence.

1.15 Survival Aspects

The landing was smooth, and deceleration forces were low throughout the landing roll. All seats remained intact, and galley equipment and carry-on baggage remained in place.

The three cabin attendants realized that the aircraft had left the runway and issued instructions for the passengers to adopt the brace position. When the aircraft came to rest, the attendants prepared to evacuate the aircraft and had opened one forward door prior to the captain's instruction over the passenger address system to evacuate the aircraft. Evacuation took place through the two forward doors, the two rear doors, and the two overwing exits.

The purser supervised the evacuation from the forward doors, one flight attendant supervised from the rear doors, and the other from the overwing exits. The procedure conformed to Pacific Western's Flight Attendant Manual.

The evacuation procedure in the flight attendant's manual contains a footnote indicating that flashlights, megaphones, and first-aid kits are to be taken off the aircraft by the flight attendants during the evacuation. The equipment was left on the aircraft.

The speedbrakes should be retracted prior to evacuation so as not to impede the passengers as they exit over the wing. In this case, the speedbrakes could not be retracted because the engines were shut down; however, no passengers reported that the extended speedbrakes impeded them. The passengers slid down the flaps to the ground; one passenger injured her ankle in the process.

1.16 Tests and Research

1.16.1 Tests at Kelowna and Calgary

The aircraft was inspected by PWA maintenance personnel after the incident, and, except for the requirement to replace all the wheels and tires, to restore the emergency equipment that was used, and to replace a brake line damaged during recovery, the aircraft was serviceable. An engine power run and reverser operational check were conducted, and the aircraft was then flown to Calgary. Further checks were made on the anti-skid system and the rigging of the spoilers and the ground air safety sensor. No faults were reported; however, independent checks were not made to determine if all components were within limits at the time of the occurrence.

1.16.2 Tests on the Ground Air Safety Sensor

Tests were carried out by CASB and PWA personnel at the PWA hangar in Vancouver on 03 October 1986 using aircraft C-GGPW and another Boeing 737 to determine the weight required to compress the right landing gear strut sufficiently to activate the ground air safety sensor and the hydraulic ground spoiler interconnect valve. These tests indicated that in order to obtain 1.5 inches of compression on a strut serviced to Boeing specifications, between 9,100 and 11,000 pounds of weight are required. Three inches of compression requires 10,300 to 12,800 pounds. These figures are close to the weights obtained from the Boeing company

which indicated that 8,000 and 9,100 pounds respectively would compress the strut by these amounts and 11,600 pounds would compress the strut five inches.

1.16.3 Flight Tests

On 29 September 1986, C-GGPW was test flown by a Pacific Western flight crew, with CASB investigators observing. The purpose of the flight was to simulate the conditions that occurred at Kelowna. However, adjustments had been made to the setting of the ground air safety sensor in the course of normal maintenance after the incident, and the tests failed to duplicate the condition. At the time of the tests, the ground air safety sensor operated at 1.5 inches of strut compression, and the hydraulic ground spoiler interconnect valve operated at 2.5 inches of compression.

1.17 Additional Information

1.17.1 Take-off Warning Horn

The take-off warning horn will sound if the ground air safety sensor signals that the aircraft is on the ground, the thrust levers are advanced beyond the idle position, and any one or more of the following conditions exists:

a) the leading edge devices are not in a take-off position;
b) the stabilizer trim is not in the take-off range;
c) the speedbrake lever is not in the down detent;
d) the trailing edge flaps are not in the take-off range of 1 through 25.

A warning horn ("beep beep" in Appendix A) sounded momentarily as Flight 117 touched down at Kelowna. Frequency spectrum analysis of the CVR identified this sound as the take-off warning horn.

1.17.2 Performance Data

During the initial certification tests for an aircraft, the required landing distance is demonstrated. These tests are carried out on a dry runway with the aircraft crossing the runway threshold at 50 feet, at a speed of 1.3 times the stall speed. The aircraft is stopped on the runway by the use of speedbrakes and maximum braking, but without the use of reverse thrust. The total distance from 50 feet to touchdown plus the length of the ground stopping distance is known as the demonstrated landing distance. This distance is then

increased by 67 per cent to provide a safety margin, and the result is called the landing distance required.

Wet runway landings for Federal Aviation Administration (FAA) pilot qualitative evaluation are performed; however, certification tests are not carried out on wet runways. For the Boeing 737, the calculated dry runway landing distance is increased by 15 per cent when landing on a wet runway. This information is presented to the pilot in graphic form in the airplane flight manual.

Using the graph and the actual landing weight of 88,426 pounds for Flight 117, the following landing distances can be calculated:

Landing Distance Available (feet)	Runway Condition	Speedbrake Operation	Anti-skid	Wind Component (knots)	Landing Distance Required (feet)
5,350	Dry	Auto	Operative	0	3,750
5,350	Wet	Auto	Operative	0	4,315
5,350	Wet	Manual	Operative	0	4,665

1.17.3 Performance Penalties

The Boeing 737 Flight Crew Training Manual describes some of the landing distance penalties incurred on a dry runway if proper landing techniques are not used. (See Appendix C. The performance penalties chart does not deal with the effects of runway contamination.) An overextended flare (three-second float) increases the landing distance by 650 feet; 100 feet over the threshold - 950 feet; speedbrakes not extended - 650 to 900 feet; speedbrakes not extended and thrust reversers not deployed - 1,000 to 2,350 feet; high approach speed (plus 10 knots) - 250 to 350 feet. Manual deployment rather than automatic deployment of the speedbrakes can add about 350 feet to the landing distance. As well, if the interlock prevents selection of reverse thrust and the reverse thrust levers are held against the interlock, substantially more than idle thrust is produced which will increase the stopping distance.

1.17.4 Landing on Slippery Runways

The PWA Airplane Operations Manual in effect at the time of the occurrence outlines the following procedures for landing on a wet or slippery runway. These procedures stress the importance of using the correct approach

speeds and touchdown point. The recommended approach speed is 1.3 times the stall speed. A correction factor of half the steady wind plus all the wind gusts is added to this speed to allow for fluctuations in the wind during the approach. The proper landing procedures require that the steady wind speed factor be bled off as the aircraft approaches touchdown and that the gust speed factor be maintained to touchdown. The touchdown aiming point is 500 to 1,000 feet beyond the threshold, and, if it cannot be achieved, a go-around is recommended. The aircraft is flown firmly onto the runway, even if speed is excessive, to ensure wheel spin-up and to ensure movement of the ground air safety sensor to the ground mode. Attached at Appendices D and E are extracts from the PWA and Boeing Manuals.

1.17.5 Effect of Reverse Thrust and Spoilers

Although reverse thrust is not used in determining the landing distance required, it plays a significant role in stopping the aircraft on a wet runway. The flight and ground spoilers, along with reverse thrust, contribute 80 per cent of the braking force at the higher speeds present during the initial landing phase. The lower the braking coefficient of friction, the greater the contribution that reverse thrust makes in reducing the landing ground roll. Performance data indicate that, at a coefficient of 0.4, the ground distance of 1,900 feet would be reduced to 1,700 feet with use of reverse thrust. At a coefficient of 0.1, a ground distance of 5,500 feet would be reduced to 3,300 feet.

Figures from the manufacturer indicate that, in the flap 40 landing configuration with the spoilers down and with the aircraft's nosewheel on the runway and at a speed of 135 knots, the aircraft's wings are capable of generating 91,427 pounds of lift. With the flight spoilers up, this lift is 52,728 pounds, and, with both flight and ground spoilers up, the lift generated is 14,633 pounds.

1.17.6 Hydroplaning

Hydroplaning is a condition that can develop whenever a tire is moving on a wet surface. The tire squeezes water from under the tread generating water pressures which can lift portions of the tire off the runway and reduce the amount of friction the tire can develop. During total "dynamic" hydroplaning, the tire lifts off the runway and rides on a wedge of water, causing such a complete loss of tire friction that wheel spin-up will not occur. On wet runways where there is not enough water to cause dynamic hydroplaning, viscous

hydroplaning can occur. This term describes the normal slipperiness or lubricating action of the water. Viscous hydroplaning does not reduce the friction to such a low level that wheel spin-up will not occur. Reverted rubber hydroplaning can occur when a locked tire is skidded along a very slippery wet runway and can be initiated at any speed above about 20 knots. The friction generates steam and the steam pressure lifts the tire off the runway. The steam heat reverts the rubber to a black, gummy substance, and the steam cleans the runway surface under the tire.

The point at which dynamic hydroplaning occurs is influenced by water depth, runway texture, tire tread depth, and tire pressure. Generally, a water depth greater than the depth of the aircraft's tire tread is required for dynamic hydroplaning. Tests have shown that the minimum speed at which dynamic hydroplaning can occur can be roughly calculated by multiplying the square root of the tire pressure by nine. The main wheel tire pressure of the Boeing 737 is approximately 170 pounds per square inch (psi). The minimum speed for hydroplaning on this aircraft is thus about 117 knots. Once established, hydroplaning can continue at speeds well below this figure.

1.17.7 B737 Overrun History

A review of the International Civil Aviation Organization (ICAO) data base for the period 1970 to 1987 revealed 14 occurrences in which a B737 ran off the end of the runway. Although many details in the occurrences are not available, there is some information which has relevance to the Kelowna incident. Nine of the 14 occurrences appear to be landing overruns, and, in four of them, it was mentioned that there was difficulty in selecting reverse thrust. In the same period, there were 12 landing-related occurrences reported for the B727 and four for the DC9. For these other two types, there was no mention of difficulty in obtaining spoiler deployment or reverse thrust.

There are also other occurrences reported through operators in which difficulty was experienced in selecting reverse thrust. The following three had some similarities to the Kelowna incident:

21 January 1985	Kelowna, B.C.	PWA
26 October 1986	Charlotte, North Carolina	Piedmont Airlines
20 October 1987	Sitka, Alaska	Alaska Airlines

In these occurrences, the flight crew experienced difficulty in stopping the airplane because of a lack of

deceleration capability. All experienced difficulty selecting reverse thrust and obtaining ground spoilers. Insufficient compression of the right main gear appears to have been a factor in these difficulties, and, in two of the cases, crew operating techniques (excess landing speed, smooth touchdown) were a factor.

1.17.8 Emergency Vehicle Response

The tower controller sounded the crash alarm as the aircraft left the runway. Two emergency response vehicles arrived at the aircraft within three minutes of the occurrence and parked near the nose of the aircraft. When the vehicles arrived, all the passengers were off the aircraft. The crew chief confirmed with the captain that the appropriate aircraft switches were off and checked that all passengers had left the aircraft.

The fire department and an ambulance from the City of Kelowna, which is located approximately five miles south of the airport, arrived at the scene 12 minutes after the incident.

1.17.9 Eyewitnesses

Eyewitness reports of the approach and landing place the touchdown point beyond 1,200 feet from the threshold. Touchdown was reported to be smooth with water spraying up behind the wheels after touchdown.

2.0 ANALYSIS

2.1 Introduction

The investigation focused on the weather, the runway conditions, the aircraft systems, the crew's performance, and how these factors combined to result in the aircraft's leaving the end of the runway.

2.2 The Weather

On initial contact with the Kelowna Tower, the flight crew was advised of the presence of thunderstorms and torrential rain at the airport. The captain decided to delay the landing until the thunderstorm activity had moved away from the airport; the approach was not commenced until the storm cell had moved to the east of the airport. The flight encountered only light rain on the approach, and the crew reported that the runway looked wet, but there was no indication of flooding. Touchdown occurred 14 minutes after the crew first received the information about the torrential rain at the airport and several minutes after the heavy rain had ceased. There was no evidence that the aircraft encountered vertical wind shear during the approach or landing.

2.3 Runway Condition

When Flight 117 touched down, a 5- to 10-knot wind was blowing 60 degrees off the runway heading. With the runway cross-fall from the crown and downhill slope, the cross-wind would tend to maintain surface water near the centre of the runway. The water would then follow the slope toward the threshold of runway 33, concentrating near the touchdown zone. The crew saw no standing water on the runway when they landed; however, 4.2 millimetres of rain fell in the previous 20 minutes, there was a total lack of braking, and the flat spots on the tires indicated that hydroplaning had occurred. The Board concluded there was still a significant amount of surface water on the runway.

2.4 The Approach

The landing reference speed, based on the aircraft's weight and flap 40 configuration, was 120 knots indicated airspeed (KIAS). The speeds to be flown during final approach and landing were determined using the reported wind of 300 degrees at 15 to 20 knots with

occasional gusts to 25. Based on the reference speed of 120 KIAS and assuming the steady wind to be 20 knots with 5-knot gusts, the final approach speed was determined to be 135 KIAS. The normal operating procedure calls for 10 knots to be bled off for landing.

The approach and landing speeds were not adjusted when lighter winds were subsequently reported by the tower. However, because of the proximity of the thunderstorm activity and the possibility of rapid changes in wind speed and direction, it is considered normal and prudent to maintain the higher speed.

2.5 The Landing

The crew reported that, as the aircraft was flared, it was caught by a gust of wind which resulted in the aircraft touching down later and smoother than planned. The aircraft touched down at approximately 135 KIAS; the 10 knots had not been bled off. The crew reported that touchdown occurred between 1,000 and 1,500 feet from the threshold, and eyewitnesses accounts place the touchdown beyond 1,200 feet. Analysis of the DFDR and CVR data was used to establish the touchdown time, and all available data were used to determine the touchdown point of between 1,500 and 1,800 feet.

The smooth touchdown on the very wet runway was not conducive to main wheel spin-up and oleo compression. The sound of the take-off warning horn on touchdown indicates that the ground air safety sensor momentarily moved to the ground mode and that the thrust levers were not at idle. The fact that the thrust levers were not at idle accounts, in part, for the extended flare and smooth touchdown. Non-compression of the ground air safety sensor or lack of main wheel spin-up prevented the speedbrake lever from automatically moving to the up position on touchdown. As the nose was lowered, ground effect, the forward control column position after touchdown, and the high airspeed combined to provide sufficient lift to allow the right main oleo to extend to the point where the sensor moved back to the air mode. Thus, the pawl (because of an above idle position of the forward thrust levers) or the interlock (because the sensor was in the air mode) prevented the crew from obtaining reverse thrust. An increase in forward thrust may have occurred while the reverse thrust levers were held against the interlock. Lack of weight on the wheels and the hydroplaning action prevented effective wheel braking.

When the aircraft was examined after the occurrence, the speedbrake lever was in the up position and all spoilers were deployed.

After the aircraft landed, it decelerated from 135 to 112 KIAS in the first 15 seconds for a deceleration rate of 1.53 knots per second. For the next three seconds, the rate was 3.33 knots per second; the DFDR then stopped. The change in the rate of deceleration after 15 seconds is coincident with a speed of 112 KIAS and a 1.3G spike in the DFDR vertical acceleration trace. Tests conducted by PWA and CASB personnel indicated that the ground air safety sensor and hydraulic interconnect valve activated when the weight on the right main gear was approximately 11,025 and 12,800 pounds respectively. At 112 KIAS, at an aircraft weight of 88,426 pounds, with the flaps at 40 degrees, and with no spoilers deployed, the weight on each main gear is calculated to be approximately 10,840 pounds.

It is concluded that, based on the very low rate of deceleration and other indications, the flight spoilers were not deployed in the first 15 seconds that the aircraft was on the ground. Had the flight spoilers deployed at or immediately after touchdown, the weight on each main gear would have been approximately 15,000 pounds, more than enough to activate both the ground air safety sensor and the hydraulic interconnect valve. The ground spoilers would then have deployed and the pilots, if the thrust levers were at idle, could have selected reverse thrust. If, at any time during the first 15 seconds of ground roll, the crew had manually deployed the flight spoilers or if the main wheels had spun up, flight spoiler deployment would have resulted in all spoiler deployment and allowed the crew to select reverse thrust; the change in the rate of deceleration would have been evident on the DFDR trace. It is concluded that, as the aircraft speed reached 112 KIAS, all the spoilers deployed, either because the crew manually moved the speedbrake lever or because the ground air safety sensor activated. The abrupt change in aircraft configuration with the attendant increase in the weight on the wheels was deemed to account for the 1.3G spike on the vertical acceleration trace.

Once the ground air safety sensor indicated on-ground, reverse thrust could have been successfully selected; however, the engines were shut down within one second after the on-ground indication. Once the engines were shut down, loss of AC power rendered the anti-skid system inoperative. As this occurred while both pilots were applying full brake, the wheels locked. The aircraft left the runway with the wheels locked as evidenced by the nature and location of the tire damage and the marks on the runway.

2.6 Air/Ground System Logic

The data base on B737 landing overruns is sparse; however, for the few occurrences reported, there have been a significant number in which difficulties achieving spoiler deployment or reverse thrust were cited as factors.

Given the right combination of environmental and operational factors, the system logic may prevent the crew from using one or more of the deceleration devices. In this occurrence, the touchdown speed and position on the wet runway created a situation in which all deceleration equipment had to function efficiently to stop the aircraft on the runway; the soft landing, hydroplaning and system logic denied the crew the use of some of this equipment. The thrust reverser override switches could have been used to bypass the system logic to allow thrust reverser operation; however, the switches are not well positioned for this function, nor is it a procedure for which flight crews have been trained.

2.7 The Operational Factors

The success of a landing on a wet or slippery runway is dependent on several factors: the amount of water on the runway, runway/tire condition, the touchdown speed, the runway length, the firmness of the touchdown, the use of power, and the deceleration devices available. In this landing, the pilots had discussed some of the operational factors but not all of them.

The runway was very wet, and the crew discussed the need to land firmly and to manually deploy the flight spoilers if they did not come up automatically. The co-pilot was aiming to touch down at the 1,000-foot marker. The crew did not discuss the touchdown speed or the throttle position desired at touchdown.

During the flare, a gust of wind caused the aircraft to float past the intended touchdown point. Both pilots knew the landing was long, and the co-pilot knew he still had some power on. The aircraft speed was not reduced in the flare, which contributed to the long landing.

The smooth touchdown was not planned. Given that the crew had agreed upon the necessity to land firmly, it is probable that the co-pilot's smooth landing was unintentional and is attributed to the wind gust. The absence of any braking was immediately noted by the crew as was the non-availability of reverse thrust. Neither

pilot noted the fact that the speedbrake lever did not move to the up position immediately after touchdown. Once the aircraft was on the ground with the brakes applied and attempts made to select reverse thrust, the crew was committed to completing the landing; it is stated in the company manual "do not attempt a go-around after reverse thrust has been initiated."

The cumulative effect was to reduce the stopping distance available, to increase the likelihood of hydroplaning, and to work against the air/ground system logic. The crew appreciated some, but not all, of these effects and therefore continued the landing after they had passed the intended touchdown point.

Had a go-around been initiated when the crew passed the intended touchdown point, the occurrence might have been avoided.

2.8 Evacuation

The evacuation of the aircraft was well-executed. Although the evacuation procedure requires them to do so, the flight attendants did not carry first-aid and other equipment with them. None of the items was needed following this evacuation; however, the procedure calls for their removal because of their potential usefulness in other circumstances.

3.0 FINDINGS

3.1 Cause-Related Findings

1. The runway was contaminated with surface water when the aircraft landed.

2. The aircraft touched down smoothly, 500 to 800 feet beyond the intended touchdown point.

3. The 10-knot wind factor was not bled off prior to touchdown.

4. Power was retained until touchdown.

5. The aircraft hydroplaned during the landing roll.

6. Lack of wheel spin-up prevented automatic deployment of the flight spoilers.

7. The weight of evidence indicates that the flight spoilers were not manually deployed immediately after touchdown.

8. The aircraft air/ground system logic prevented deployment of the ground spoilers and thrust reversers. Coupled with the hydroplaning action, this reduced deceleration to the extent that the aircraft could not stop on the runway.

9. Although the approach and landing procedure increased the runway length required, a go-around was not initiated.

3.2 Other Findings

1. The thrust reverser override switches could be used to bypass system logic to allow thrust reverser operation; however, the switches are not well positioned for this function, and flight crews have not been trained for this procedure.

2. The aircraft crew was certified and qualified for the flight in accordance with existing regulations.

3. The aircraft was certified, equipped, and maintained in accordance with existing regulations and approved procedures.

4. There was no evidence found of any airframe failure or system malfunction prior to or during the flight.

5. The weight and centre of gravity were within the prescribed limits.

4.0 SAFETY ACTION

4.1 Action Taken

4.1.1 The CASB notes the following action taken as a consequence of this occurrence.

a. Pacific Western Airlines issued two Flight Operations Bulletins to all its pilots concerning wet or contaminated runway operations. These bulletins reviewed the manufacturer's recommended procedures to be used during "the approach to" and the "landing on" wet or contaminated runways and highlighted the possible consequences if these procedures are not rigidly followed.

b. In the 1/87 issue of the Aviation Safety Letter, Transport Canada published an article which summarized a number of recent overruns involving transport-category aircraft that have occurred at Canadian airports to remind aircrews that wet or contaminated runways can drastically reduce braking performance.

4.1.2 Prompted by reports of pilot inability to obtain effective braking while landing at above normal speeds during adverse runway and weather conditions, the Federal Aviation Administration (FAA), on 08 June 1988, issued a Notice of Proposed Rule Making (NPRM), applicable to Boeing Model 737-100 and 737-200 series aircraft. This NPRM proposed a new airworthiness directive which would require modifications to the Air/Ground Sensing System on the Boeing 737-100/737-200 to allow thrust reverser activation to be enabled by a second means in addition to the existing logic.

4.2 Action Required

4.2.1 Wet Runway Landing Performance - Flight Crew Awareness

The CASB has knowledge of 16 occurrences involving aircraft weighing more than 12,500 pounds overrunning the runway on landing in Canada between 1980 and 1987. Most of these involved runways where the braking action was reduced by water or other surface contaminants. Canadian operators routinely conduct flight operations on wet or otherwise contaminated runways that are at or near the certified performance limits of aircraft within their fleets. The latitude for error is small. The anticipated stopping distances contained in aircraft flight manuals will not be achieved if braking action is poor.

As well, other landing performance penalties may occur as a result of the pilot technique employed. Inaccuracies during the approach and landing phases, such as high approach speed, high threshold-crossing height, extended flares, over-reliance on automatic stopping devices, and a variety of other pilot-induced factors, can increase the landing run required. The combined effect of these penalties can be significant and has, on occasion, exceeded the safety margins currently provided for in approved landing performance figures.

The flight crew in this occurrence elected to continue with the landing on a very wet runway, notwithstanding the fact that the aircraft crossed the threshold with more airspeed than required and the touchdown was smooth and longer than planned. The chance of experiencing some form of hydroplaning under these circumstances was high. The CASB is concerned that flight crews do not sufficiently appreciate the cumulative effect of the performance penalties that can be incurred when less than optimum approaches are flown or when the manufacturer's recommended techniques are not followed. Therefore, the CASB recommends that:

> The Department of Transport ensure that the recurrent training of flight crews of transport-category aircraft emphasizes the cumulative performance penalties and the uncertainties of expected stopping distances associated with operations on wet or contaminated runways. Particular emphasis should be placed on the need for a timely decision to effect a successful go-around.
>
> CASB 88-05

4.2.2 Air/Ground Logic Systems

The use of air/ground logic systems in modern aircraft provides reasonable assurance that certain aircraft systems will not activate at inopportune times. Uncommanded or inadvertent activation of flight spoilers, ground spoilers, thrust reversers or wheel brakes when not required can and have had disastrous results. The loss of a McDonnell Douglas DC-8 in Toronto in 1970 demonstrates the consequences should ground spoilers be prematurely deployed. Conversely, the inability to activate the various deceleration devices can also have disastrous consequences.

Deceleration of the Boeing 737-200 is highly dependent upon the compression of the main-gear struts. The air/ground logic system is designed to prevent deployment of engine thrust reversers and ground spoilers in flight; it receives data that indicate the airplane is on the ground when the right gear strut is compressed five inches or more, or that it is in the air when the strut is within one-half inch of full extension. At a strut compression between one and one-half inches and three inches, the hydraulic system interconnect valve provides hydraulic pressure to the ground spoiler actuators, thereby allowing ground spoiler activation. The flight spoilers, when armed, are automatically deployed following wheel spin-up or five inches of strut compression on touchdown. Flight spoiler activation as a result of wheel spin-up begins the lift reduction process to assist strut compression. However, hydroplaning can result in a lack of wheel spin-up precluding auto-deployment of the flight spoilers, thereby contributing to inadequate main gear strut compression. Insufficient strut compression or weight on the wheels can decrease the effective tire footprint, also adversely affecting braking efficiency.

The Board is concerned that failure of the strut to sufficiently compress, for whatever reason, can lead to a situation where little or no effective deceleration is available to the flight crew. While the instances of such occurrences on the Boeing 737-200 are rare, they have occurred.

Given the large number of B737s operating worldwide, thousands of landings are conducted every day, often on performance-limited contaminated runways. Since the ground spoilers and thrust reversers as well as braking efficiency are dependent upon strut compression, situations could arise where the B737 may not have sufficient deceleration means available to stop if the right main strut is insufficiently compressed. The Board recognizes that aircraft design and modification cannot preclude all possible problems with stopping an airplane. In this case, however, modifications should be considered as a means of increasing the safety margin.

Therefore, the CASB recommends that:

> The Department of Transport consider modifications to the Boeing 737-200 air/ground logic system to ensure that some means for aircraft deceleration is available to the pilot, regardless of the amount of the right main gear strut compression.
>
> CASB 88-06

4.3 Safety Concern

4.3.1 Landing Certification Standards - Transport Category Aircraft

At the present time, the certification standards used for determining the landing distance applicable to transport-category aircraft certified under Federal Aviation Regulation (FAR) 25 require that the tests be conducted on bare, dry, smooth, hard-surfaced runways. These certification trials are flown by experienced pilots anticipating the event being measured and certified and are normally flown under optimum conditions. The use of reverse thrust is not included in the certification process, because of uncertainties regarding the availability and reliability of these devices under all conditions; hence, the performance data available to flight crews for calculating deceleration and stop distances do not include the extra deceleration offered by these devices.

Subsequent to the overrun of a Boeing 737-200 at Wabush, Newfoundland on 20 July 1986 following a rejected take-off below V1, the CASB issued Recommendations 87-45 and 87-46. These recommendations addressed the absence of certification performance data and the apparent lack of knowledge on the part of flight crews regarding wet runway take-off performance.

The Board is equally concerned that the aircraft certification criteria currently in existence for ascertaining contaminated runway landing performance data do not provide aircrew with sufficiently accurate data upon which to base landing decisions. Current procedures provide for safety margins that are derived from factoring the dry landing distances by arbitrary amounts. Consequently, flight crews often land on performance limited runways using performance data for which there is no empirical evidence to assure a stop on the available runway.

Following a public hearing into the issue of runway overrun accidents subsequent to a DC 10 landing overrun accident in 1982, the National Transportation Safety Board (NTSB) issued 17 safety recommendations to the FAA. These recommendations specified the need for improved reporting of braking action by pilots and controllers, improved pilot and controller training programs, continued research and development of friction measuring devices, and the development of better stopping performance data on wet or contaminated runways for inclusion in airplane flight manuals.

The Board notes the proposed guidelines and recommendations with respect to contaminated runway operations contained in FAA draft Advisory Circular 91-6B; nevertheless, the Board is concerned that pilots continue to have no means for reliably assessing deceleration performance under less than the ideal conditions used during the certification process. Lack of awareness by aircrew with respect to the certification process for contaminated runway operations may compound the issue. In particular, the situation can develop during the landing sequence, as it did in this occurrence, where it becomes impossible to stop the aircraft on the runway remaining without the effective use of reverse thrust - yet reverse thrust effectiveness is not considered in the certification process.

The Board appreciates the difficulty in attempting to provide quantifiable landing performance data to aircrew and accepts the current practice of non-inclusion of the effects of thrust reversers on landing performance data; nevertheless, the Board will continue to monitor occurrences of runway overrun in order to further assess the possible requirement to amend the certification procedures for transport category aircraft.

This report and the safety action therein has been adopted by the Chairman, K. J. Thorneycroft and Board Members:

W. MacEachern
A. Portelance
F. Thurston

Members N. Bobbitt and L. Filotas dissented in part as follows:

We believe that the crew's actions and decisions during the approach and touchdown met the norms to be expected from qualified professionals. The first abnormal indication available to the crew came when reverse thrust could not be selected. By this time, it was no longer possible to initiate a go-around safely. Accordingly, we disagree with Cause-Related Finding Number 9 which implies that the decision not to initiate a go-around was a causal factor in this accident.

To the remaining findings, we would add that: Certification criteria for large transport aircraft do not adequately account for the increased stopping distance which may be required on runways contaminated by water to an extent that must be occasionally expected. We would recommend that the Department of Transport consider adopting field length requirements determined from performance trials on wet runways, along the lines that have been adopted by the certification authority in the United Kingdom.

Member D. Mussallem dissented in part as follows:

It is my opinion that all aspects of the approach up to the touchdown point were within the bounds of prudent and normal operation for the existing conditions. The approach speed was prudent, taking into account the latest recommended approach procedures (re wind shear) when thunderstorms are in the area. Under gusty conditions, it is sometimes easier said than done to bleed off 10 knots prior to touchdown. Also, even if the touchdown had been 500 feet sooner and the speed 10 knots less but everything else being the same, the aircraft would have still departed the far end of the runway at a speed in the neighbourhood of 60 to 70 knots.

I do not agree with Cause-Related Finding Number 9. If the ground spoilers and thrust reverse had functioned as they were expected to do, there would have been no need for a go-around. The first unusual event was when reversing was initiated, but the buckets would not deploy: "It doesn't want to come into reverse." It is a firm rule in this aircraft that, after reverse is initiated, a go-around shall not be attempted. This being the case, Finding Number 9 does not make sense as the crew was committed to remain on the ground.

An excellent article on the technical aspects of this particular incident and other similar B-737 overruns appeared in the January 1988 issue of ALPA Airline Pilot and was reprinted in the April 1988 issue of CALPA Pilot.

The B-737 is equipped with ground spoilers and thrust reversers that provide excellent initial landing deceleration. The problem is that they have sometimes failed to deploy when they were needed the most. The reason for this is covered in this report and centres around the air/ground sensors not going into the ground mode. The vulnerability of this system to failure due to mechanical damage, improper rigging, overfilled oleos, etc., points out the need for a simple backup system.

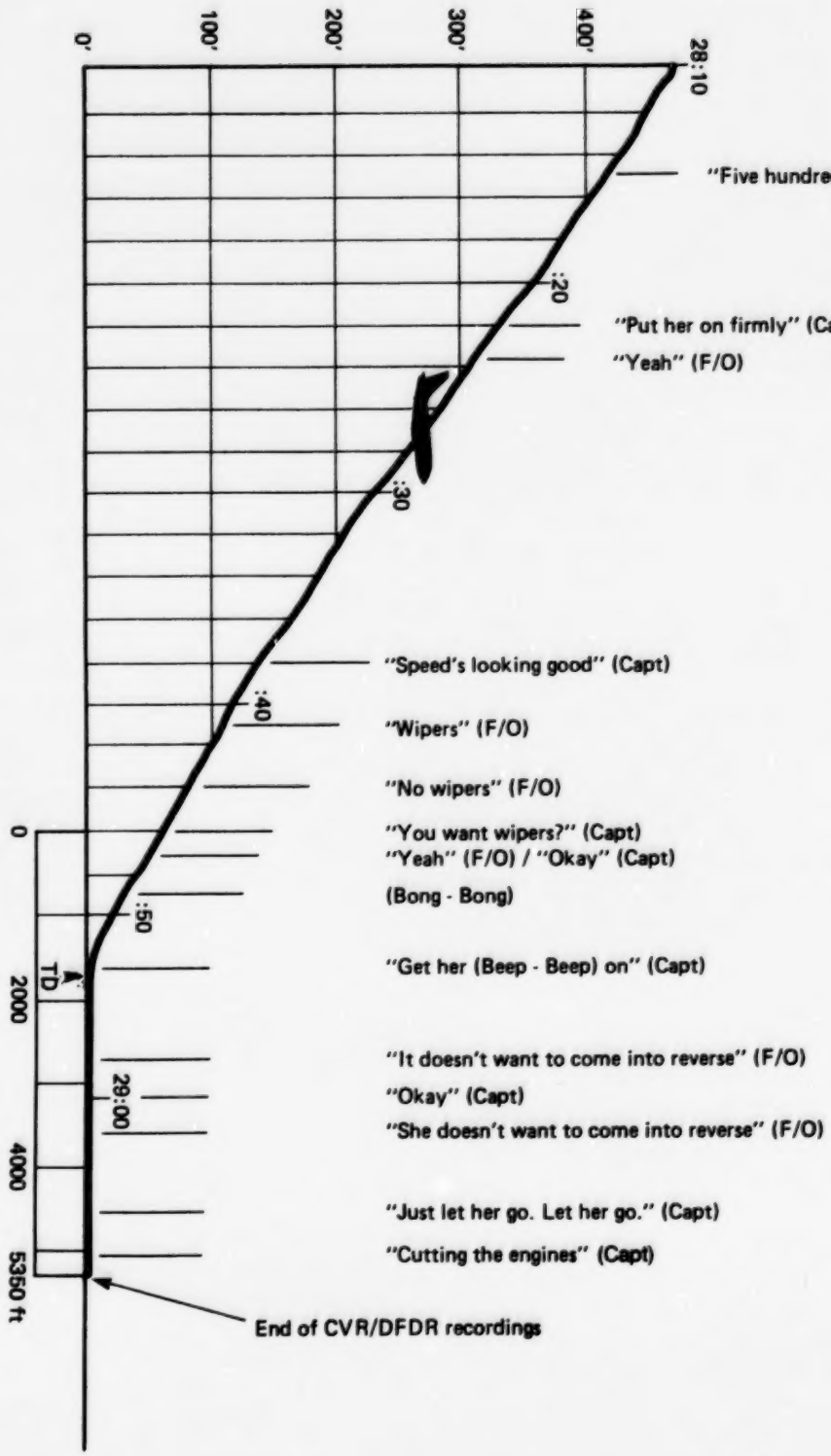
I propose a single guarded "panic" switch, located centrally on the glareshield or forward overhead panel, easily reached by either pilot. Throwing this switch would immediately put the spoiler and reverse system into the ground mode so that subsequent manual deployment of the speedbrake lever would give immediate ground spoiler, and reverse lever movement would give guaranteed thrust reverse. Reverse could be actuated manually prior to manual speedbrake actuation or vice versa. It is very possible that some B-737 overruns are caused by failure of auto spoiler function and the crew failing to notice this and subsequent crew concentration on the inability of getting into reverse when the sequence of flight spoilers are first required to kill lift, depress the oleo to bring the system into ground mode before reverse can be engaged. I realize the existing thrust reverser override switches can perform the reverser function of the proposed "panic" switch, but their location is not ideal, and they have no effect on the ground spoiler operation. When operating into 5,000-foot strips, it is imperative that crews be given a backup to immediately engage the stopping devices. At Kelowna, there was only 3,500 feet of runway left after touchdown to stop a 130-knot aircraft. I sympathize with the frustration the crew must have felt during those few seconds of helplessness prior to the overrun.

This incident brings into question the capability of transport aircraft to stop in the distances claimed in the manuals by the manufacturer and certifying agency. In many cases, they won't stop as advertised, and, in the real world of line flying with contaminated runways (and even clean runways), overruns are going to continue to happen. Even more potentially dangerous are rejected take-offs at or near V_1 when the aircraft is at maximum weight for the runway length. Although these aborts are rare, I doubt if most cases that the aircraft would stop in the distance the manuals indicate prior to overrunning.

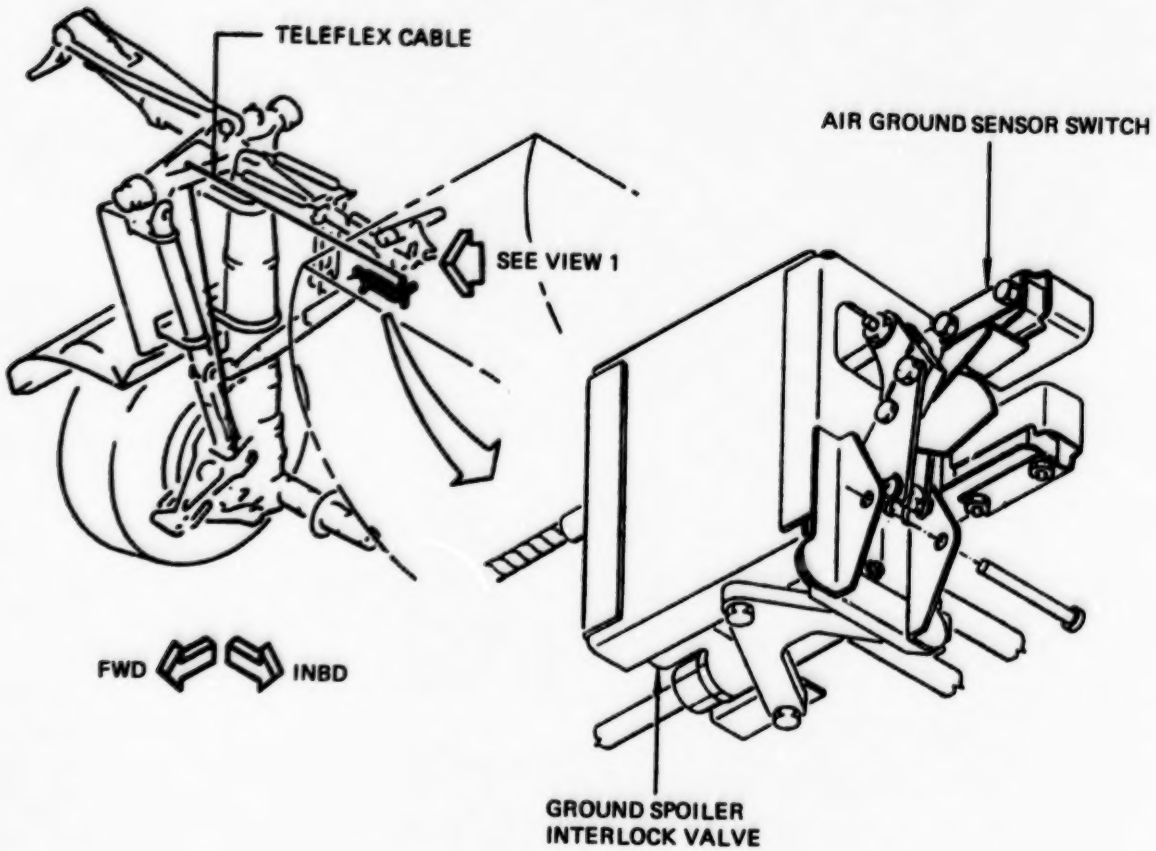
It is my opinion that there is a reluctance by industry and the pertinent government agencies to properly address this potential safety hazard and so these accidents will continue to happen. This should not be the case.

FINAL FLIGHT PATH

FLIGHT DECK COMMUNICATIONS

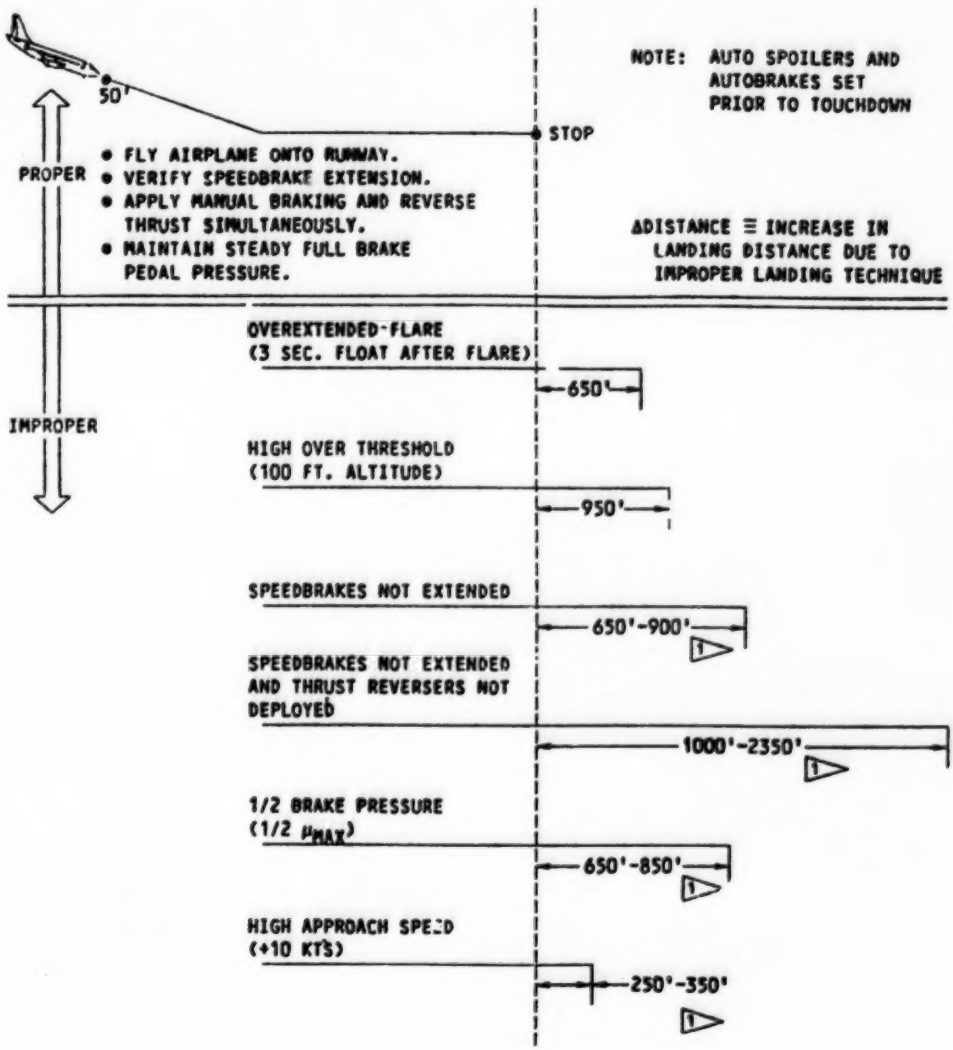


LANDING GEAR SAFETY SENSORS



FACTORS AFFECTING LANDING DISTANCE

BOEING 737
FLIGHT CREW TRAINING MANUAL



1 LANDING DISTANCE VARIES WITH RUNWAY CONDITION. WET OR DRY. DATA DOES NOT INCLUDE CONTAMINATED RUNWAY CONSIDERATIONS.

FACTORS AFFECTING LANDING DISTANCE
MAXIMUM EFFORT STOP
FLAPS 40

APPROACH PLANNING (CONT)

Reference speed (Vref) is 130% of stall speed (1.3 Vs) in the landing configuration. When the wind is reported calm or light and variable, and no wind shear exists, Vref + 5 knots is the recommended airspeed on final, bleeding off the 5 knots as the aircraft approaches touchdown.

It is recommended that a wind gradient factor equal to one-half the reported headwind be added mentally to the Vref on final. If gusts are also present, the full value of the gusts plus the wind gradient factor are added to Vref up to a total of 20 knots maximum. If both gust and wind gradient factors have been added to Vref, only the gust factor should be retained to touchdown.

Flaps 30 or 40 are normally used for landing because of better speed stability.

On runways 7000' or more in length use flaps 30.

Flap 40 Landing

In gusty conditions do not use flap 40 for landing on the advanced airplane when the bug speed plus wind exceeds 145 KIAS.

Flap blow back could inadvertently occur near the ground and cause an uncontrollable and excessive sink resulting in a short landing.

Landing flare should be performed by use of elevator control only.

When making a VOR or ADF approach, descent to minimum altitude as soon as practical after passing the final fix inbound with gear down, flaps 15 and 150 knots. Visually align the airplane with the runway and set up a normal final approach.

When the runway is sighted and a straight-in landing can be accomplished, select the landing flap setting and establish the landing profile.

The pilot should not dive at the runway when breaking clear of the clouds at low altitudes from an instrument approach. High rates of descent that develop with this maneuver are not readily apparent on either the airspeed indicator or the vertical speed indicator, and may not be noticed until the flare point.

DESCENT – APPROACH PROCEDURE

Normally at FL 200 or top of descent on flights below FL 200, on the Captain's command, the Captain and First Officer will perform the descent and approach procedure and then the First Officer will read and respond to the DESCENT AND APPROACH checklist.

Anti-Ice.....AS REQUIRED

When icing conditions exist or are anticipated, use engine anti-ice and state switch position. Use wing anti-ice system to de-ice the wing as required.

Air Conditioning
and Pressurization.....SET

If in STANDBY, the landing field elevation (-200) should be set in the controller.

#Gravel Protect Switch.....AS REQUIRED

If landing on gravel the gravel protect switch should be ON. If engine anti-ice is required the gravel protect switch should be in the ANTI-ICE/TEST position.

Start Switches.....LOW IGN

Altimeters and
Instruments.....SET AND X-CHECKED

Both pilots reset and crosscheck altimeters to local altimeter setting when descending through local Transition Altitude. Crosscheck flight instruments and set radios for approach and landing. Set radio altimeter to appropriate altitude. Check proper setting on altitude alert.

TAT/EPR and
IAS Bugs.....CHECKED AND SET

Set landing flap selector to desired landing flap and set the airspeed bug ON the airspeed indicated by the Vref pointer.

If the Vref indicator is inoperative determine the Vref speed from the quick reference chart.

Set TAT/EPR mode selector to GA position. Go around EPR will read correctly only at go around altitude.

If the TAT/EPR is inoperative, obtain the ground temperature and set go around EPR bugs from the quick reference chart.

If landing on a gravel runway, start the APU at 10,000 ft.

Flap Extension – Prior Landing

For improved service life, the flap extension schedule should be observed. Maneuver the airplane so that it is decelerating through the correct air speed for the flap being used and continue decelerating on the speed schedule. Using flaps as speed brakes is not recommended.

At 210 kts	Select flaps 1
At 190 kts	Select flaps 5
At 170 kts	*Select flaps 15
At 170 kts	***Select flaps 10
At 150 kts	**Select flaps 25
At 140 kts	**(*)Select landing flap (30/40)

*Landing flap configuration ADVANCED

**Landing flap configuration BASIC

***Flaps 10-Advanced 737

The only procedures currently in use using flap 10 is the Loss of system A hydraulics and manual reversion. Full maneuvering capability is available down to 150 knots.

With landing flap maintain an airspeed of BUG plus 1/2 wind component and full gust (up to a maximum of 20 kts).

 # Gravel Operation Only

PACIFIC WESTERN AIRLINES

LANDING PROCEDURES

As the aircraft approaches the touchdown point, reduce descent rate, smoothly retard thrust to idle and maintain the flight profile to touchdown. Use speed brakes, brakes, and reverse thrust normally after touchdown. On gravel runways do not use reverse unless required. The aileron and rudder controls are effective down to approximately 50 knots.

In the event of a bounced landing, hold or re-establish normal landing attitude. Add thrust as necessary to control the sink rate. Do not push over, as this may cause a second bounce and possibly damage the nose gear.

The First Officer will:

- Check speedbrake full up.
- Monitor REVERSER UNLOCK lights for normal operation.
- Monitor engine instruments.
- Advise Captain of any engine limit being approached, exceeded, or any other abnormality.

- Observe REVERSER UNLOCK lights extinguished.

GO-AROUND PROCEDURE

Apply go-around thrust and rotate to go-around attitude.

Select flight director to GA.

Retract flaps to 15.

Retract the landing gear when a positive rate of climb is indicated.

At bug +15 knots, select flaps 5. Climb thrust

At 170 knots, select flaps 1.

At 190 knots, select flaps UP.

Check leading edge lights OUT.

Crosswind

The crab, sideslip, or a combination of both are accepted methods for correcting for a crosswind during approach and landing. Regardless of which method is used, there is sufficient rudder and aileron control available to execute crosswind landings.

Use rudder and rudder pedal steering to hold the airplane on centerline. Displacing the aileron into the wind will assist in directional control. Nose wheel steering will be improved with a slight forward pressure on the control column which increases weight on the nose gear.

Flap Extension

The following procedures, configuration, and normal maneuvering speeds are used when flying normal traffic patterns.

Initial pattern entry: at 210 knots select flaps 1

At 190 knots, select flaps 5.

Reduce speed to 170 knots.

Just prior to turning base lower landing gear and select flaps 15.

At 150 knots, select flaps 25.

At 140, select landing flap.

Reduce speed to Vref speed + 5 (no wind) or reduce speed to bug + 1/2 wind + gust.

Speed Brakes

With the speed brake lever in the armed position, all spoilers will rise automatically when the thrust levers are retarded to IDLE and the right main gear touches down and the wheels spin up. The spoilers destroy lift and place most of the weight of the aircraft on the wheels for effective braking during initial landing roll.

Speed Brakes (Cont)

At touchdown, if the spoilers do not extend automatically, immediately move the speed brake lever to the up position and simultaneously apply the brakes and reverse thrust.

WARNING: IN THE EVENT OF A GO-AROUND ON THE RUNWAY AFTER REVERSE THRUST HAS BEEN INITIATED AND CANCELLED IT IS POSSIBLE TO APPLY GO-AROUND THRUST BEFORE THE THRUST REVERSERS ARE FULLY STOWED AND LOCKED. AS SOON AS THE AIRCRAFT LEAVES THE RUNWAY, THE STOWAGE SEQUENCE WILL BE INTERRUPTED DUE TO CLOSURE OF THE HYDRAULIC ISOLATION VALVE WHICH SHUTS OFF HYDRAULIC PRESSURE TO THE THRUST REVERSER SYSTEM AND IT WILL BE POSSIBLE TO FLY THE AIRCRAFT AT NORMAL THRUST WITH THE REVERSERS PARTIALLY OPENED. INCREASING AIRLOADS DURING THE OVERSHOOT WILL THEN MOVE THE REVERSER DOORS INTO THE FULL REVERSE POSITION AND SIMULTANEOUSLY FORCE THE THRUST LEVER TO THE IDLE POSITION.

DO NOT ATTEMPT A GO-AROUND AFTER REVERSE THRUST HAS BEEN INITIATED. FAILURE OF A THRUST REVERSER TO RETURN TO THE FORWARD THRUST POSITION MAY PREVENT A SUCCESSFUL GO-AROUND.

Reverse Thrust

CAUTION: LOWERING OF THE NOSE SHOULD BE INITIATED BEFORE ACTUATING REVERSE THRUST TO PREVENT THE REVERSER DOORS FROM CONTACTING THE RUNWAY.

Brake and tire wear can be reduced by proper use of reverse thrust.

At touchdown, immediately start lowering the nose before initiating reverse thrust. Rapidly raise the reverse thrust levers and move them aft to the interlock, then to the reverse thrust, detent No. 2. Modulate reverse thrust as required and avoid exceeding engine limits. Conditions permitting limit reverse thrust to 1.5 EPR for passenger comfort.

CAUTION: SUBSTANTIALLY MORE THAN IDLE FORWARD THRUST IS PRODUCED WHEN THE INTERLOCK ON THE THRUST REVERSER/S PREVENT MOVING THE REVERSE THRUST LEVER/S INTO THE REVERSE RANGE. HOLDING THE REVERSE THRUST LEVER/S AGAINST THE INTERLOCK UNDER THESE CONDITIONS WILL INCREASE THE BRAKES ONLY STOPPING DISTANCE.

At temperatures below approximately 0 degrees F (-18 degrees C), after No. 2 detent is felt, immediately move reverse thrust levers forward, modulating thrust to maintain power within engine limits.

When required, the maximum allowable go-around EPR (or AFM limit EPR if operating on gravel runway) may be used. At 60 knots, gradually reduce reverse thrust so as to be at no more than 1.1 EPR when reaching taxi speed.

When operating on gravel, unpaved, or contaminated runways, limit reverse thrust as much as possible (idle reverse recommended) consistent with landing conditions and runway length available for stopping to prevent foreign object damage and increase service life of the engines. At 80 knots, modulate to idle reverse and return to forward thrust by 60 knots.

Flaps

Operation on contaminated runways may result in foreign object damage to the flaps. In order to minimize damage to the flaps the pilot not flying the airplane will place the flap handle to 15 immediately after touchdown. The effect on stopping distance using this procedure is negligible.

Taxi-Out (Cont)

Light gross weight

Any combination of the above

When using reverse thrust to reduce taxi speed, a smooth rearward movement of the reverse levers is desired to avoid overshooting the limit of the interlock position. If an EPR of more than 1.1 results, modulate the reverse thrust levers forward until 1.1 EPR or less is reached. The 1.1 EPR indication will normally preclude foreign object ingestion and air conditioning contamination. If the odor of exhaust gases is detected, or excessive dust is generated, return the thrust levers to forward thrust to avoid contamination. Reverse thrust for taxi should be used with caution on airports known to have dirty runway or taxi conditions.

Takeoff

High temperatures inflict performance penalties which must be taken into account on the ground before takeoff. When the effects of high temperatures are combined with short runways, gravel operation or high elevation airports, performance penalties may affect the payloads which can be carried. Consideration should be given to using alternate takeoff procedures (No Bleed Takeoff, Improved Climb Performance, etc.). Fuel temperature limitations listed in the Limitations Section must be observed.

Landing

See "LANDING ON WET OR SLIPPERY RUNWAYS" in this section.

Brake Cooling

Flight crews should be aware of brake temperature buildup when operating a series of short flight sectors and attempt to maintain cool brakes by additional inflight cooling prior to each landing to prevent ground delays resulting from overheated brakes and possible loss of main wheel fuse plugs at enroute stops. A series of short flight sectors without additional inflight brake cooling can cause excessrive brake temperatures as the energy absorbed by the brakes from each landing is accumulative.

Extending the gear a few minutes early in the approach will provide sufficient cooling for a landing with cool tires and brakes. Inflight cooling time can be determined from the "Brake Cooling Schedule" in the Performance Section of the Operations Manual.

Close adherence to recommended landing rollout procedures will ensure minimum brake temperature buildup.

LANDING ON WET OR SLIPPERY RUNWAYS

Operate the airplane during the approach in a way that will minimize stopping requirements after touchdown without running the risk of landing short.

Plan for a touchdown 500 to 1,000 feet from the approach end of the usable runway. Prior to touchdown, move the feet up on the step bar to be prepared for immediate brake application after touchdown.

Maintain close control over approach speeds and maintain speed recommended for the existing conditions. The recommended wind additives (1/2 steady wind plus full gust to a maximum of 20 knots) provide adequate safety margins for both the approach and the landing roll.

LANDING ON WET OR SLIPPERY RUNWAYS (CONT)

Control glide slope path to accomplish touchdown on the runway at 500 to 1,000 feet from the approach end of the runway. The airplane should be flown firmly onto the runway at the aiming point even if speed is excessive. If an unsatisfactory approach is likely to cause touchdown far down the runway, go around and make a second approach. Once the airplane has been landed and the stopping effort begun, attempting a go-around is not recommended.

If the wing anti-ice system is inoperative and large ice formations remain on wing leading edge or leading edge flaps, 10 knots may be added (at pilot's discretion) to the reference speed to maintain normal handling characteristics.

Crosswind

In crosswind conditions, the crosswind crab angle should be maintained to touch down on very slippery runways. Allowing the airplane to touch down without removing the crab angle will reduce drift toward the downwind side of the runway on wet or icy runways. Auto spoilers and auto-brakes (if installed) will operate sooner when all main gear touch down simultaneously, thus establishing main gear crab effect sooner and reducing pilot workload.

Touchdown and Landing Roll

Once on the ground, the importance of timing during the early use of all means of stopping the airplane cannot be overemphasized. Timely execution of the following actions will permit stopping the airplane with the least landing roll.

Check that the auto speedbrakes (if installed) deploy immediately after the main gear contacts the runway. If the speedbrake lever fails to actuate automatically (or not installed) immediately actuate it manually. Speedbrakes will reduce lift, increase drag and increase main gear loading. Quick extension of the speedbrakes is important because the effects of reduced lift and increased drag are additive in shortening landing roll.

Immediately lower the nose wheel as the speedbrakes and thrust reversers are being actuated. This is desirable because establishing the airplane in a taxi attitude decreases lift, increases main gear loading and improves directional stability. Holding the nose off and delaying braking is undesirable as aerodynamic braking is relatively ineffective.

Use thrust reversers as soon as possible during landing roll. Thrust reversers are most effective at high speed.

At touchdown, immediately start lowering the nose before initiating reverse thrust. Rapidly raise the reverse thrust levers and move them aft to the interlock, then to the reverse thrust, detent No. 2. Modulate reverse thrust as required and avoid exceeding engine limits. Conditions permitting, limit reverse thrust to 1.5 EPR for passenger comfort.

At temperatures below approximately 0 degrees F (-18 degrees C), after No. 2 detent is felt, immediately move reverse thrust levers forward, modulating thrust to maintain power within engine limits.

LANDING

Charts are provided for the determination of the maximum landing gross weight as limited by FAR runway or climb requirements.

Performance for each certificated landing flap setting is provided. In general, use of the greatest flap setting consistent with structural and climb limits is recommended.

The runway charts present data for the dry and wet runway requirements defined by the FAR regulation. For all landings at or near the runway-limited gross weight, close attention to landing technique is desirable. In particular, it is advantageous to avoid excess final approach speeds, or touch down beyond the 1000 foot point. On ILS equipped runways, the runway available beyond the intersection of the ILS glide slope and the runway should also be considered. Better deceleration is achieved by the simultaneous use of speed brakes, wheel brakes, and thrust reversers with the aircraft on the ground, than by bleeding off excess speed while floating. The thrust reversers are most effective at higher speeds; accordingly, expeditious application of reverse thrust after touchdown will provide the best deceleration. Refer to Section 3A for detailed landing procedures and techniques.

Landing Under Adverse Runway Conditions:

When a landing is to be made on a runway during adverse runway conditions, careful attention to the above procedures is recommended.

Automatic deployment of the speed brakes is dependent upon a spin-up signal from the main wheels. This spin-up signal could be delayed when landing in standing water or extremely slippery runways; therefore, the pilot should be prepared to operate the speed brake lever manually, if required.

APPENDIX F

GLOSSARY

AC	alternating current
agl	above ground level
asl	above sea level
ATC	air traffic control
CASB	Canadian Aviation Safety Board
CVR	cockpit voice recorder
DFDR	digital flight data recorder
FAA	Federal Aviation Administation
FAR	Federal Aviation Regulation
hr	hour(s)
ICAO	International Civil Aviation Organization
IFR	instrument flight rules
JBI	James Brake Index
KIAS	knots indicated airspeed
lat	latitude
lb	pound(s)
long	longitude
MEA	minimum en route altitude
N	north
NDB	non-directional beacon
NPRM	Notice of Proposed Rule Making
NTSB	National Transportation Safety Board
N1	fan or low pressure compressor speed
PDT	Pacific daylight time
psi	pounds per square inch
PWA	Pacific Western Airlines
rpm	revolutions per minute
RSC	runway surface condition
VASIS	visual approach slope indicator system
W	west
^{o}	degree(s)
'	minute(s)